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# The Role of Working Memory Capacity in Math Performance

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by

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Abstract

Several studies have noted that those with higher working memory capacity show the most pronounced negative relationship between math anxiety and math performance. The current study was interested in whether expressive writing would improve math performance for people with math anxiety. And if so, whether the rate of improvement was better for those with low or high working memory capacity? 62 university students (21 male, *M* = 23.33) comprised the sample for the study. Using a repeated measures factorial design, writing was manipulated by splitting participants into an expressive condition (experimental group), and into a neutral writing condition (control group). Both groups also completed a math anxiety survey, a math test and a memory task. The study did not find evidence that expressive writing improves math performance. However, we did find that individuals with high working memory capacity performed better than individuals with low working memory capacity as the difficulty of math problems increased. Individuals with high working memory capacity may have more cognitive resources to draw on when task complexity increases and, thus, are better able to meet such challenges. Findings calls for interventions that help low working memory capacity individuals increase their math knowledge and math skills through learning more advanced problem solving strategies.

# The Role of Working Memory Capacity in Math Performance

Mathematics is one of the most fundamental aspects of life. Despite this, certain individuals experience great worry and apprehension when confronted with math. This concept is known as math anxiety. Math anxiety, defined by Ashcraft & Moore, (2009) is feelings of tension, apprehension, and fear of situations involving mathematics and is associated with poor math performance. Despite normal performance in most reasoning and thinking tasks, individuals with math anxiety perform poorly when the task involves numerical information (Maloney & Beilock, 2012). This often leads to substantial negative consequences. For example, for math anxious individuals, simply thinking about math, opening a math textbook or even entering a math classroom can elicit a negative emotional response.

Interestingly, and paradoxically, those with higher working memory capacity show the most pronounced negative relationship between math anxiety and math achievement (Ramirez, Gunderson, Levine, & Beilock, 2013). In other words, individuals with the greatest capacity to excel in math do not, because when anxious, their working memory becomes flooded with negative self-talk, which then reduces the efficiency and use of effortful strategies that help high working memory capacity individuals perform at a high level in math. Due to the negative consequences associated with math anxiety, especially for individuals with the capacity to excel in math, identifying ways to reduce its deleterious effects is essential. In the current study, knowledge about the cognitive mechanisms by which math anxiety relates to math performance is used to test an intervention designed to boost math- anxious students' performance on math tasks.

## How does Math Anxiety Develop?

The dominant view adopted by educators and researchers was that math anxiety only emerged in the context of complex mathematics such as algebra, and thus was not present in young children (Maloney & Beilock, 2012). Math anxiety was thought to develop in high school, due to the increasing difficulty of the math curriculum (Hembree, 1990). However, recent research has shown that children as young as first grade report varying levels of anxiety towards math, which is inversely related to their math achievement (Ramirez et al., 2013). When performing mathematical calculations, math anxious children, relative to their less anxious counterparts, show hyperactivity in their right amygdala regions, which is important for processing negative emotions (Ramirez et al., 2013). This increased amygdala activity is accompanied by reduced activity in brain regions known to support working memory and numerical processing (e.g. dorsolateral prefrontal cortex and posterior parietal lobe) (Young, Wu, & Menon, 2012).

In regards to the antecedents of math anxiety, Maloney & Beilock (2012) have demonstrated that both social influences and cognitive predispositions play a role in the onset of math anxiety in early elementary school. Regarding social influences, studies note that children's math attitudes form as a result of an interaction with parents and teachers. According to Gunderson, Ramirez, Levine, & Beilock, (2012) parents' and teachers' expectations for children's success in math are biased by their own gender stereotypes. These gender-biased expectations lead to lower achievement and lower math-self concepts among girls than boys. Similar to how social norms are passed down from one generation to another, negative math attitudes seem to be transmitted from teacher to student, and/or from parent to child (Gunderson et al., 2012).

As mentioned, some individuals may also have a cognitive predisposition to develop math anxiety. In adults, math anxiety is associated with deficits in one or more of the fundamental building blocks of mathematics (Maloney & Beilock, 2012). For example, several studies by Maloney and colleagues have reported that adults who are math anxious are worse than non math anxious adults at counting objects (Maloney, Risko, Ansari & Fugelsang, 2010), at deciding which of two numbers represents a larger quantity (Maloney, Ansari, Fugelsang, 2011) and at mentally rotating 3D objects (Maloney, Waechter, Risko & Fugelsang, 2012). Comparable to how people who lack knowledge in a particular area are often easily swayed by negative messages, children who start formal schooling with deficiencies in these mathematical building blocks may be especially predisposed to pick up on social cues (e.g. their teacher's behavior) that highlight math in a negative way (Maloney & Beilock, 2012). Because math is an inevitable part of life, especially throughout formal school, it is important to understand the mediating factor between math anxiety and math performance because, it may impair individuals from not only excelling in math, but it can limit their career choices (Betz & Hackett, 1983).

**Relationship between Math anxiety and Math Performance**

Research suggests that the relationship between math anxiety and subsequent math performance is due to a reduction in working memory capacity, which is often brought on by negative self-talk flooding the individuals working memory (Ramirez, Gunderson, Levine, & Beilock, 2013). Working memory capacity reflects one's ability to apply activation to memory representations, to either bring them into focus or maintain them in focus, particularly in the face of interference or distraction (Engle, Kane, &

Tuholski, 1999). In this case, it refers to an individual's ability to use advance problem solving strategies they learned to perform math problems while distracted.

Along those lines, Beilock and Carr (2005) found support for distraction theories on choking under pressure, according to which, like anxiety, pressure creates mental distractions that compete for and reduce working memory capacity that would otherwise be allocated to skill execution. This work suggests that compromises of working memory capacity cause failure in tasks that rely heavily on this system. However, knowledge of the causal mechanisms governing suboptimal performance is only part of the key to understanding failure. To truly understand undesirable skill decrements, and to develop training interventions to alleviate them, one must also identify characteristics of those individuals most likely to fail. As stated, those with higher working memory capacity show the most pronounced negative relation between math anxiety and math achievement (Ramirez et al., 2013). When faced with a math related task, high math anxious individuals tend to worry about the situation and the consequences that might result. This suggest that math anxiety may negatively influence math performance by inhibiting the limited working memory resources that are crucial for successful math problem solving (Ashcraft & Kirk, 2001; Ashcraft & Moore, 2009; Engle, 2002; Young et al., 2012).

In fact, individuals with higher working memory capacity have been demonstrated to show a greater deployment of advanced strategies and overall higher math achievement than their lower working memory peers (Beilock & Carr, 2005). Consistent with Beilock & Carr, (2005), Ramirez et al., (2013) demonstrated that anxiety-related worries inhibit the working memory resources that individuals rely on to support advanced memory-based strategies, thus making it difficult for high working memory capacity individuals to use the advanced memory-based strategies they otherwise would use. In other words, higher math anxiety may reduce the efficiency and, hence, use of effortful strategies that help high working memory individuals to perform at a high level in math. By contrast, individuals lower in working memory might be less susceptible to the math anxiety-induced disruptions to working memory because they typically rely on rudimentary strategies (e.g., counting) that are less demanding of working memory resources and also associated with lower math achievement (Barrouillet & Lépine, 2005). In light of this, it is essential that researchers find ways in which to relieve math anxiety, in order to give individuals with the potential to excel in math a chance to be successful.

**Expressive Writing as an Intervention for Math Anxiety**

According to Park, Ramirez and Beilock (2014), previous attempts at reducing the detrimental impact of math anxiety on math performance have primarily focused on improving the math skills of high math anxious individuals, while paying less attention to addressing the worry component of math anxiety (e.g. Bander, Russell, & Zamostny, 1982; Simon & Schifter, 1993). Park et al., (2014) believed that, because math anxiety impacts the individuals working memory, flooding it with non math related thoughts and worries, then eliminating or reducing this effect on working memory would allow the individuals to focus on the math task and perform to their potential. One way of doing this is through expressive writing.

Expressive writing is a simple, clinical technique that encourages individuals to write freely about their thoughts and feelings regarding an important stressor they are facing (Pennebaker & Beall, 1986). Several studies have demonstrated that writing about a stressful or emotional event for 15–20 minutes can (after several sessions of writing across time) provide both physical and psychological benefits for clinical (e.g., depressed patients; Gortner, Rude, & Pennebaker, 2006) as well as nonclinical populations (e.g., first year college students; Klein & Boals, 2001). Moreover, expressive writing has also been demonstrated to increase the availability of working memory resources (Klein & Boals, 2001). After three 20-min writing sessions, college students who wrote about their thoughts and feelings regarding college life demonstrated significant gains in working-memory availability in comparison to those who wrote about a trivial topic (Klein & Boals, 2001). The research suggests that expressive writing can help reduce the impact of stressful exam situations on performance.

Recently, Ramirez and Beilock (2011) demonstrated that individuals who were instructed to write for 10 minutes about their feelings and thoughts about an upcoming exam (taken in a contrived laboratory setting) performed significantly better than those who did not write or wrote about an unrelated topic. Furthermore, it was shown that writing about negative thoughts and ruminations helps explain the benefits of expressive writing on high-stakes test performance. The benefits of expressive writing even extend to the classroom, where students must contend with acute stress derived from final examinations (Ramirez & Beilock, 2011), as well as standardized tests such as the Medical College Admission Test (MCAT).

Using the aforementioned work, Park et al (2014) explored whether expressive writing could reduce the negative impact of math anxiety on math performance. To do this, the authors randomly assigned low math anxious and high math anxious individuals, to either write about their worries (expressive writing group) or to sit quietly (control group) before an exam. After seven minutes of either writing or sitting quietly, all participants took an exam that consisted of both math and word problems, varying in the demands it placed on working memory. Park et al., (2014) found that when high math anxious individuals are tasked with solving math problems requiring high working-memory demands, they perform significantly worse than their low math anxious counterparts, which was consistent with the aforementioned research by (Ramirez et al., 2013). Park et al., (2014) results suggest that many students may have a long history of suffering the deleterious effects of math anxiety. Despite the pervasive experience of math anxiety, their study shows that after a single bout of expressive writing, one can significantly reduce the extent to which math anxiety relates to individuals' math performance.

Although Park et al., (2014) demonstrates significant benefits of expressive writing for high math anxious individuals, the authors do not explicitly show individual differences in math performance after expressive writing. As aforementioned, individuals with the greatest potential to excel in math (High working memory capacity individuals) don't because of their high level of math anxiety. It is essential to specifically show which individuals benefited the most from expressive writing, as it can help educators and program makers know which type of interventions are helpful for each group. For example, based on the reviewed literature, expressive writing might help only high working memory capacity individuals, because it would relieve their working memory of the negative self-talk that inhibits them. Whereas individuals with low working memory capacity might benefit from tutoring or other means of interventions.

In light of this, the current study was aimed at further investigating the role of expressive writing in reducing the negative effect of math anxiety on high working memory capacity individuals' math performance. If the individuals with the greatest potential to excel in math are given a single session of expressive writing before completing a high working memory demand math task, would there be an increase in performance? More specifically, our study was interested in whether expressive writing would improve math performance for people with math anxiety. And if so, was the rate of improvement better for those with low or high working memory capacity?

**Current Study**

The current study evaluated the effect of expressive writing on the math-anxiety–math-performance relationship, especially amongst high working memory capacity individuals. In our study, knowledge about the cognitive mechanisms by which math anxiety relates to math performance was used to test an intervention designed to increase math- anxious students' performance on math tests. Using a repeated measures factorial design, writing was manipulated by splitting participants into an expressive condition (experimental group), where they were asked to write about their math related worries, and into a neutral writing condition (control group), where they were asked to write about everything they had done that day and how they might have done a better job. After seven minutes of writing, all participants completed the math test consisting of math problems varying in the demands they placed on working memory (Low or High working memory demand). All participants also completed a working memory capacity task to determine the level (low or high) of their working memory capacity. Their overall math performance was determined using their response time (RT) and accuracy of their response (Error Rate). Additionally, given that math anxiety is often comorbid with general test anxiety (Betz, 1978), it is possible that the math- anxiety–math performance relationship is inflated by general test anxiety (Devine, Fawcett, Szucs, & Dowker, 2012). Therefore, measures of students' test anxiety were collected and used as a covariate in the analyses.

Specifically, the following hypotheses were tested:

- It was predicted that individuals in the expressive writing condition would outperform the control writing condition on the math test.
- Secondly, it was predicted that the positive effect of the expressive writing would be greatest for high math anxious individuals with high working memory capacity.
- Thirdly, it was predicted that high working memory capacity individuals would outperform their low working memory capacity counterparts.

## Method

### Participants

64 undergraduate students were recruited on a convenience and voluntary basis (through SONA system) to participate in the study. However, two participants were excluded from the study due to incomplete responses, making it a total of 62 participants (21 male, $M$ = 23.33 years, $SD$= 6.30). All participants completed their primary and secondary education in North America, had English as their first language, received their elementary and high school math education in English, and had reported normal or corrected-to-normal vision. Psychology 1000 students had the opportunity to receive up to 2.5% bonus marks for completing a related assignment. Additionally, second year psychology students received credit for participating in the study.

## Materials

**Math Anxiety.** The Abbreviated Math Anxiety Scale (AMAS; Hopko et al., 2003) is a nine item self-report questionnaire used to measure math anxiety. Items on the AMAS were responded to using a 5-point Likert-type scale, ranging from 1 (low anxiety) to 5 (high anxiety), in terms of how anxious they would feel during the event specified. For example, "Having to use the tables in the back of a math book;" 1, *low Anxiety*, 2, *some anxiety*, 3, *moderate anxiety*, 4, *quite a bit of anxiety*, 5, *high anxiety*. The total score represents a summation of the nine items, with possible scores ranging from 9 to 45. A median split was used to determine their level of anxiety such that high scores on the scale indicate high math anxiety. Reliability analysis produced a high level of internal consistency $\alpha = .82$

**Test Anxiety.** Measures of students' test anxiety were collected using a 27-item self-report questionnaire (Cognitive Test Anxiety Scale; Cassady & Johnson, 2002). Items for the test-anxiety questionnaire asked individuals to rate how anxious they would feel during general testing situations (e.g., "I tend to freeze up on things like intelligence tests and final exams;" 1, *not at all typical of me*; 2, *only somewhat typical of me*; 3, *quite typical of me*; 4, *very typical of me*). Items number 3, 5, 8, 9, 10, 13, 17, 18, 21, were reversed, therefore were recoded to produce consistency in scale so that high values always reflect high cognitive test anxiety responses (i.e. higher scores indicate higher cognitive test anxiety). Using a sum of all the items, the possible range of sum scores was from 27 to 108. A median split was used to determine their level of anxiety. The scale demonstrated a high level of internal consistency $\alpha = .92$.

**AOSPAN**. The Automated Operation Span (Unsworth, Heitz, Schrock & Engle, 2005) is an easy-to-administer and automated version of a popular working memory capacity task (operation span; OSPAN) developed by Turner and Engle's (1989). AOSPAN can be administered on an Ipad, scores itself, and requires little intervention on the part of the experimenter. It is shown that this version of Ospan correlates well with other measures of working memory capacity and has both good internal consistency ($\alpha$ =.78) and test-retest reliability ($r$ =.83). AOSPAN involves solving a series of math problems while attempting to remember a list of letters of the alphabet. Individuals are presented with one equation-letter string at a time [e.g., (5x2) - 2 = 8? H] on an Ipad and asked to verify whether the equation is correct by tapping true for the correctly solved problems and false for the incorrectly solved problems. In all experimental conditions, the math problem presented is timed with a 5500ms cut off. Therefore, participants were asked to solve the problems as quickly as possible without sacrificing accuracy. If participants took too long, the program automatically moved on and counted that trial as an error. The 5500ms cut off was well above average task response times established by Lyons and Beilock (2012). Following the math problem, participants were asked to memorize the corresponding letter. At the end of each series, participants were asked to recall the list of letters that remained on screen for 500ms. At recall, the participants saw a 4x3 matrix of letters (F, H, J, K, L, N, P, Q, R, S, T, and Y). Recall consisted of tapping the box next to the appropriate letters in the correct order. Furthermore, the recall phase was untimed. Letters are used because previous research suggests that some of the shared variance between span tasks that use words and a measure of higher order cognition, such as reading comprehension, is due to word knowledge (Engle, Nations, & Cantor, 1990).

Moreover, each series consisted of two to six strings, and the order of string length was determined randomly. Individuals were tested on two series of each length. This made for a total of 40 math problems and 40 letters. Additionally, the order of set sizes was randomized for each participant. At the end of the task, the program reported five scores to the experimenter: Ospan score, total number correct, math errors, speed errors, and accuracy errors. The first, Ospan score, used Turner and Engle (1989) absolute scoring method. This was the sum of all perfectly recalled sets. So, for instance, if a participant correctly recalled three letters in a set size of three, four letters in a set size of four, and three letters in a set size of five, his or her Ospan score would be 7(3 4 0). The second score, "total number correct," was the total number of letters recalled in the correct position. Three types of errors were reported. "Math errors" were the total number of task errors, which was then broken down into "speed errors," in which the participant ran out of time in attempting to solve a given math operation, and "accuracy errors," in which the participant solved the math operation incorrectly. The task took approximately 5–7 minutes to complete. The dependent variable was their total Ospan score.

The **Expressive Writing** task was adopted from Park et al., (2014). Participants were asked to write about their deepest thoughts and feelings about the upcoming math exam (done on paper). More specifically, participants in the expressive writing condition read the following statement: "Please take the next 7 minutes to write as openly as possible about your thoughts and feelings regarding the math problems you are about to perform on the Ipad. In your writing, I want you to really let yourself go and explore your emotions and thoughts, as you are getting ready to start the set of math problems. You might relate your current thoughts to the way you have felt during other similar situations at school or in other situations in your life. Please try to be as open as possible as you write about your thoughts at this time. Remember, there will be no identifying information on your essay. None of the experimenters, including me, can link your writing to you. Press the enter key at the end of every sentence to start a new sentence in the next row. When I knock on the door please stop writing and cover up the text so that I can't see what you wrote."

The **Neutral Writing** task was adopted from Ramirez and Beilock (2011). Participants were asked to write about everything they had done that day. More specifically, participants read the following statement: "Please take 7 minutes to write about everything you did today. While writing, describe how you might have done a better job. Please be as objective in your description as possible. Remember, there will be no identifying information on your essay. None of the experimenters, including me, can link your writing to you. When I knock on the door please stop writing and cover up the text so that I can't see what you wrote"

**Math Test.** A set of math problems created by Lyons and Beilock (2012) were used as stimuli for the math test. Participants were presented with simple arithmetic problems on an Ipad in the form of (a x b) - c = d, where a $(a \times b) - c = d$, where $a \neq b$, $c > 0$, $d > 0$. Participants were asked to verify whether the problems were solved correctly or not by tapping "True" for the correctly solved problems and "False" for the incorrectly solved problems. The math test consisted of 30 math problems with high working-memory demands (termed hard questions) and 30 math problems with low working-memory demands (termed easy problems). Hard math problems were operationalized as those in which $5 \leq a \leq 9$, $5 \leq b \leq 9$ ($a \times b \geq 30$), and $15 \leq c \leq 19$. In addition, subtracting $c$ from ($a \times b$) always required a borrow operation, for example, $(6 \times 9) - 15 = 39$. Easy math problems were operationalized as $1 \leq a \leq 9$, $1 \leq b \leq 9$ ($a \times b \leq 9$), and $1 \leq c \leq 8$. In addition, subtracting c never required a borrow operation, for example, $(3 \times 2) - 4 = 2$. Hard math problems involved higher numbers and borrowing operations, whereas problems with easy problems involved lower numbers and no borrowing operations. The order in which the type of math problem (easy and hard) were presented was randomized between participants. Each problem had a 5500 ms cut off; therefore participants were encouraged to solve the problem as quickly as possible without sacrificing accuracy. Furthermore, a 1500-ms cue was presented between each question. Lastly, at the end of the math test, two scores were reported to the experimenter, error rates and RT.

The **Math Background and Interests Questionnaire** is a shortened version of the Math Background and Interests Questionnaire (MBIQ) –Canada Version, developed by LeFevre et al., (2003). The Questionnaire consists of 20 items. Of the 20 items, 11 items involved demographic questions such as sex, age, and major in school. Three items, on a 5-point likert scale involved their overall math attitudes (e.g. Please rate your level of basic mathematical skill [e.g., skill at arithmetic]: *1 very low, 2 low, 3 moderate, 4 high, 5 very high*). The remaining six items involved their language and writing skills (eg. Please rate your written language skills [e.g., writing a paper for a college course]: *1 very low, 2 low, 3 moderate, 4 high, 5 very high*).

**Procedure**

Each participant was individually tested in a single session lasting approximately 35 minutes. After reading and signing the consent form, the math anxiety scale was administered first, followed by the general test anxiety scale. Next, the AOspan task was administered. Participants were then randomly assigned to either the expressive writing or the neutral writing (control) group and asked to follow the instructions on the paper while the experimenter left the room. After 7 minutes of writing, the experimenter entered the room and instructed the participant to hand in their paper. Immediately following, participants in both groups completed the math test, which was done on an Ipad. After completion of the math test, participants then completed the Math Background and Interest Questionnaire. Lastly, participants were verbally debriefed, given a paper copy of the debriefing form, and thanked for their time.

## Results

A 2 (Writing group: expressive, control) x 2 (Math anxiety: low, high) x 2 (Working memory capacity: low, high) x 2 (Problem difficulty: easy, hard) repeated-measures factorial ANOVA was performed separately for math error rate and RT. There were no significant main effects of writing group for either RT $F$ (1, 54) = .40, *ns* or error rate $F$ (1, 54)= .92, *ns*. Likewise, there were no significant main effects of math anxiety for RT $F$ (1, 54) = .20, *ns* or for error rates $F$ (1, 54) = .86, *ns*. Additionally, there were no significant interactions involving these two variables for either error rate $F$ (1, 54)= .20, *ns* or RT $F$(1, 54)= .51, *ns* (power ranged from .07– .16). However, there was a problem difficulty effect, such that, participants made more errors for hard ($M$ = 51.50%) than easy problems ($M$ = 8.40%), $F$(1, 54) = 457.32, $p$ < .001. Participants were also slower to solve hard ($M$ = 3790 ms) than easy problems ($M$ = 2830 ms), $F$ (1, 54)=

190.99, $p < .001$. Furthermore, there was an effect of working memory capacity on RT. Participants with high working memory capacity were faster to solve math problems ($M$ = 3137ms) than participants with low working memory capacity ($M$ = 3483 ms), $F$ (1, 54) = 7.47, $p$ = .008. Lastly, as shown in *Figure 1*, there was an interaction between working memory capacity and problem difficulty for math error rate, $F$ (1, 54) = 4.15, $p$ = .047. Specifically, the problem difficulty effect was greater for individuals with low working memory capacity.

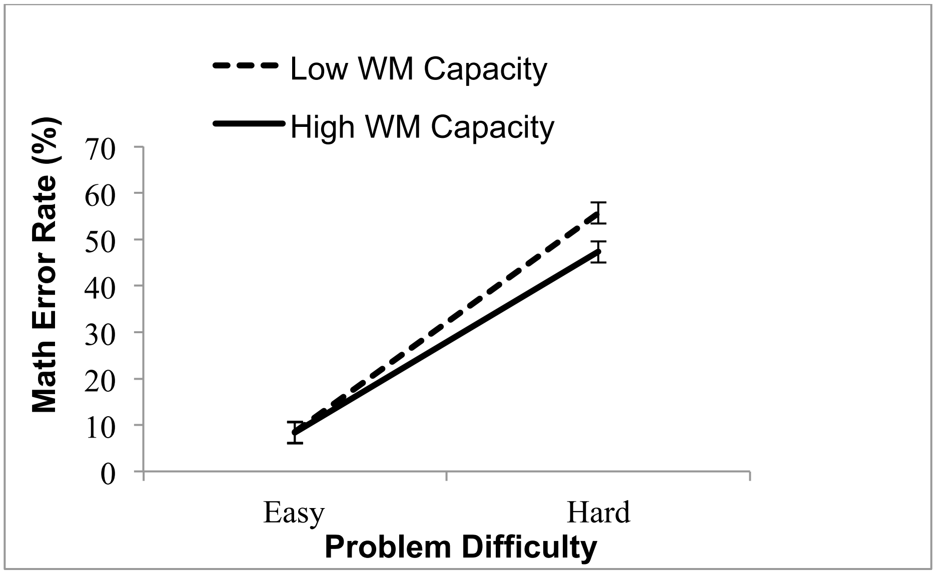


*Figure 1*. The effect of problem difficulty as a function of working memory capacity.

Error bars reflect 95% confidence intervals (Jarmasz & Hollands, 2009).

## Discussion

We examined whether expressive writing would improve math performance for high math anxious individuals, and if so, whether the rate of improvement would be better for those with low or high working memory capacity. We did not find evidence to support whether individuals in the expressive writing condition outperformed the neutral writing condition on the math test. Furthermore, we did not find evidence to support our second hypothesis that the positive effect of the expressive writing would be greatest for high math anxious individuals with high working memory capacity. However, in support of our third hypothesis, we found that high working memory capacity individuals outperformed their lower working memory capacity counterparts, specifically, for the math RT. We also found a significant interaction between problem difficulty and working memory capacity for math error rates.

### Does Expressive Writing Improve Math Performance for Math-Anxious Individuals?

While Ramirez and Beilock (2014) found that expressive writing reduced math anxiety, resulting in a higher math performance than individuals in the control group, the current study was not able to replicate these findings. This may be due to the small sample size used for this study; inspecting the power, there was only an 11% chance of finding an effect for math RT and a 10% chance for the math error rate. Additionally, inspecting themes in responses to both the expressive and neutral writing task, it is evident that most participants in the neutral writing condition did not understand the instructions; as they were asked to write about everything they did that day (i.e. from the moment they woke up until the time of testing). Instead, some participants in the neutral writing condition wrote about the experiment, their worries, and fears regarding the math portion of the Aospan. This then, may have cancelled out the effect of expressive writing, as it is in the expressive writing condition alone that participants are to explicitly write about their math fears and worries. Perhaps, the control condition should have waited patiently instead of writing (e.g. Park et al., 2014), or clearer instructions should have been provided indicating that they are to just write generally about what they did from the moment they woke up. While this might be one reason, it is highly unlikely because there were no statistically significant difference between the two math anxiety groups. This suggests that both high and low math anxious individuals performed similarly on the math test. Perhaps, Park et al., (2014) were able to find a difference in high math anxious and low math anxious individuals' math performance because they had pre-screened participants prior (low math anxiety was classified as scores below 20, high math anxious was classified as scores above 40) to participating in their main study in order to get a more dichotomous split between the two groups, thereby reducing any potential noise.

Nevertheless, as expected, we found that high working memory capacity individuals outperformed their low working memory capacity counterparts. Specifically, we found support for participants' math RT; such that, high working memory capacity individuals took less time to solve the math problems than low working memory capacity individuals. This finding follows past studies that show that high working memory capacity individuals are quicker to answer math problems than low working memory individuals (Beilock & Carr, 2005; Beilock & DeCaro, 2007; Ramirez & Beilock, 2011). Moreover, it suggests that it is advantageous to have a high working memory capacity, as you're able to solve math problems faster. Additionally, in line with Lyons & Beilock

(2012), a significant interaction was found between problem difficulty and working memory capacity. This finding indicates that when problems were relatively easy (i.e., no carry required), participants with low and high working memory capacity performed equally well. However, when the working memory *demands* of the task increased (i.e., hard problems, requiring a carry operation), participants with high working memory capacity were less affected than those with low working memory capacity. Thus, this further supports our previous finding of high working memory capacity individuals outperforming their lower working memory counterparts. It shows that while both groups performed equally well on the easy problems, when the task complexity increases (i.e. the problems get more difficult) individuals with high working memory capacity are better equipped to handle such challenges because they have more cognitive resources to draw on. Whereas, individuals with low working memory capacity typically rely on rudimentary, basic math strategies that would seize to be helpful when the math problems require advanced math knowledge and strategies (Ramirez et al., 2016).

Working memory capacity refers to the ability to focus attention on a central task and execute its required operations while inhibiting irrelevant information (Beilock & Carr, 2005; Kane & Engle, 2000). According to the distraction theory; the reason why you see a performance difference when the task complexity increases is due in part to those individuals high in working memory capacity's ability to focus in the face of interference, thus, they are better able to tune out irrelevant information and focus on the task at hand (Beilock & Carr, 2005). However, the current study did not include interference or distraction element in the experiment, therefore, this explanation would not apply. Instead, it is more likely that individuals with high working memory capacity have more advanced problem-solving strategies, thus, when the problem difficulty increases, they are able to draw on those strategies they learned during formal schooling, to aid them (Ramirez et al., 2016). In fact, at the beginning of formal schooling, when learning to solve math problems, children typically rely on rudimentary problem solving strategies. It is through repeated practice and use of rudimentary problem solving tactics that children develop strong problem-answer relationships that allow them to transition to more advanced problem solving strategies such as decomposition and retrieval (Ramirez et al., 2016). Thus, it would suggest that while rudimentary problem solving strategies are effective on the low working memory demand (easy) math problems, when the demand placed on high working memory increases (hard math problems), one requires advanced problem solving strategies to be able to solve the harder problems. This notion better explains why low working memory capacity individuals perform comparable to high working memory capacity individuals on the easy math problems, yet when the math problems get more difficult, they make more errors than high working memory capacity individuals, as they use less advanced problem solving strategies. Additionally, this logic also explains why there wasn't a significant interaction of working memory capacity and problem difficulty on participants' math RT. This is because both retrieval and decomposition along with other advanced problem solving strategies are taxing on one's working memory resources. Even though advanced memory-based strategies (e.g., decomposition, retrieval) may seem effortless after extended practice, these strategies initially place high demands on working memory, requiring individuals to retrieve facts directly from long-term memory, inhibit competing answer choices, and maintain intermediate steps (DeStefano & LeFevre, 2004, Geary et al., 2004, Ramirez et al., 2016).

Because of the demand it places on one's working memory resources, it may explain why this study did not find a significant effect for math RT, as the use of advanced problem solving strategies requires more time.

In short, while we did not find support for the role of expressive writing in math performance, or an effect of math anxiety on math performance, which may be due to the study's limitations, we did find a role of working memory capacity on math performance. The findings show that a person's working memory capacity plays a vital role in their ability to solve math problems, particularly when the problem difficulty increases.

**Study Implications**

An individuals working memory capacity tends to be domain specific, and as improvements in working memory capacity can only be done through repeated practice, these findings calls for interventions centered on improving one's math skills. Although, it is noted that this may be more difficult for low working memory capacity adults because it means that they would have to get a tutor or take math classes, and dedicate an immense amount of time to learning and practicing the math problem solving strategies they should have learned during their years of schooling. However, as a preventive measure, policy makers should invest in programs that can help children struggling in math before this performance gap widens. A delay in developing a diverse selection of strategies may not only limit children's math performance but also affect their flexible mathematical thinking more generally and reduce their conceptual understanding of mathematics (Rittle-Johnson and Star, 2007 and Rittle-Johnson et al., 2009). This can have negative long-term impacts as one's math knowledge is related to the development of math anxiety, their decision to enroll in post-secondary school (Betz & Hackett, 1983) and their career choices (Parker, Marsh, Ciarrochi, Marshall, & Abduljabbar, 2014).

Furthermore, although children use a mixture of strategies to solve math problems of various difficulty levels throughout development (Beilock & Carr, 2005), the use of advanced memory-based strategies is important throughout all stages of schooling (Ramirez et al., 2016). Advanced memory-based strategies provide foundation for more complex math and are associated with higher conceptual understanding and achievement in math (Ramirez et al., 2016). Thus, it calls for policy makers and educators to help people transition to using advanced memory based strategies. Perhaps, the focus should be on helping teachers and (capable) parents expose children to diverse math problem strategies (Rittle-Johnson and Star, 2007). In fact, Marsh and Craven (2006) suggest that enhancing students' math knowledge through either skill development or self-enhancement strategies may be an effective way to improve math performance.

**Limitations**

One main limitation previously mentioned is in regards to the small sample size. Perhaps with a larger sample, we would have had enough power to find an effect of expressive writing on high math anxious individuals’ math performance. Furthermore, as mentioned, the instructions for the neutral writing task caused some confusion for participants. Perhaps clearer instructions would have remedied this problem. Or perhaps, participants in the neutral writing condition should have waited patiently instead of writing (Park et al., 2014). Another limitation is regarding the population used. Our study consisted of university students from a predominately white university. This reduces the generalizability of our findings, as it is not representative of the general population.

**Future Research**

This study recognizes that there are many contextual factors that can affect a person's math performance and strategy use, including the quality of math instruction (Jordan & Levine, 2009) and access to resources that relate to academic achievement (Ramirez et al., 2016). Therefore, the differing results between low and high working memory capacity individuals may not be fully mediated by their use of advance problem strategies, but by other contextual cues. Future research should investigate other environmental cues (e.g. quality of teaching, family SES) that would lead to the difference in math performance. Additionally, future research could investigate the role of IQ regarding working memory capacity and their subsequent math performance, as IQ tends to be related to math performance, it is plausible that there would be a link between IQ, working memory capacity and math performance, as well (Engle, Tuholski, Laughlin & Conway 1995; Engle et al., 1999). Furthermore, as individuals who perform well in math tend to have a stronger math self-efficacy and higher math self-concept (Parker et al., 2014), future research should investigate whether there is a link between math self-efficacy, math self-concept and working memory capacity.

**Conclusion**

Overall, while we did not find evidence to support the role of expressive writing in high math anxious individuals' math performance, we did find support for the role of one's working memory capacity in their math performance. The results suggest that higher working memory capacity individuals generally show a greater deployment of advanced strategies and overall higher math achievement than their lower working memory capacity peers. This finding gives way for more research and interventions to be put towards helping the individuals most likely to struggle in math, as one's lack of math knowledge or lack of advanced problem solving strategies can have negative and long lasting impacts.

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